Does perceptual belongingness affect lightness constancy?

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Abstract

The relation between perceptual belongingness and lightness perception has always been studied in the contrast domain (Benary, 1924, Psychologische Forschung, 5, 131-142). Indeed, scientists have shown that two equal gray patches may differ in lightness when belonging to different reflecting surfaces. In the present work, we extend this investigation to the constancy domain. In a CRT simulation of a bipartite field of illumination, we manipulated the arrangement of 12 patches**:** 6 Squares and 6 Diamonds. The same-shape-patches could be placed: i) All within the same illumination field; or ii) Forming a row across the illumination fields. Furthermore, we manipulated proximity among the patches closer to the illumination edge. They could be i) Touching (forming an X-junction); or ii) Not Touching (not forming an X-junction). Observers were asked to perform a lightness match between two additional patches, one laying in light and the other in shadow. We found better lightness constancy when the same-shape-patches formed a row across the fields, with no effect of X-junctions. Since lightness constancy is improved by strengthening the belongingness across the illumination fields, we conclude that belongingness factors might help the visual system to aggregate the differently illuminated surfaces, and facilitate the scission process.

1 Introduction

Perceptual belongingness refers to the subsumption of some set of apparent elements into a perceived whole (Wertheimer, 1923/1939). In agreement with Gestalt theories, processes of perceptual belongingness may affect lightness perception.

The relationship between belongingness and lightness perception was first demonstrated by Benary (1924/1939). In figure 1, the small grey triangle inside the black triangle is surrounded by a lower amount of black than the small grey triangle outside the black cross. Furthermore, the grey triangle is always adjacent to the white along the hypotenuse and adjacent to the black along the catheti. Nevertheless, the small grey triangle inside the black triangle appears lighter than the identical triangle outside the black cross. Therefore, Benary concluded that belongingness affects lightness contrast.

FIGURE 1 ABOUT HERE

After Benary's findings, other scientists related lightness perception to perceptual belongingness.

Wolff (1933) analyzed the relationship between apparent depth and surface colour. The author measured the lightness difference of two target surfaces suspended in front of two different induction fields, one black and the other white. Changing the manner in which the targets were suspended by thin threads they appeared to be coplanar, whereas when the targets were fastened by two visible rests they always appeared in front of the induction field. The author found that the lightness of the targets differed only when they appeared to lie on the same depth plane of the inducing fields.

The Munker-White configuration (Munker, 1970, White, 1979) puts in evidence the role of the collinearity (even if, probably, some other factor is contributing to strengthening the effect). As can be observed in figure 2, the gray patches coaxial with black strips seem lighter than those coaxial with white, despite the fact that they all share the same luminance.

FIGURE 2 ABOUT HERE

Agostini and Proffitt (1993) produced lightness contrast configurations by using common fate and figural alignment as perceptual organization principles.

When two identical gray dots (targets) were placed randomly on a blue background, together with a collection of black and white dots, they, of course, appeared to share the same shade of gray. However, as soon as all the dots started to move but the trajectory of the black dots collection (plus one of the 2 gray targets) was orthogonal to the trajectory of the white dots collection (plus the other target), the lightness of the target moving with the black collection appeared lighter than that moving with the white one (figure 3).

FIGURE 3 ABOUT HERE

Furthermore, the authors found that when the black and white dots were arranged in different columns, a gray dot aligned with the black ones appeared to be lighter than an identical gray dot aligned with the white dots (figure 4).

FIGURE 4 ABOUT HERE

Agostini and Galmonte (2002) demonstrated that belongingness factors might even overcome the effects of local surround in determining simultaneous lightness contrast.

The medium-gray dashed lines of the cube surrounded by the light background, in figure 5, appear to be lighter than the medium-gray dashed lines of the cube placed on the dark background. According to the authors, this contrast effect occurs because the medium-gray dashed lines are contrasted by the colour of the inducer corners. Indeed, the dashed lines are necessary to complete the cube and therefore they belong to the corners which, being of a different colour, affect the lightness of the dashed lines.

FIGURE 5 ABOUT HERE

Summarizing, all the above mentioned works demonstrated that a gray patch might look darker than another equally reflecting patch if the former belongs to lighter surfaces than the latter. Therefore, authors have demonstrated that perceptual belongingness might create contrast effects.

However, it was never investigated if perceptual belongingness might affect lightness constancy.

Indeed, the link between perceptual belongingness and lightness perception was studied only by showing that lightness constancy affects perceptual belongingness. This investigation was conducted by Rock, Nijhawan, Palmer, and Tudor (1992). The authors showed that surfaces are grouped together when they share the same reflectance rather than the same luminance.

The aim of the present work is to understand if perceptual belongingness may improve lightness constancy defined in terms of a perfect luminance ratio match.

Already in 1911, Katz (1911, 1935) demonstrated that in poorly articulated visual scenes, a dimly illuminated patch looks darker than an equal reflecting patch standing in highlight. Therefore, the author demonstrated that one crucial factor for lightness constancy achievement is the “articulation of the visual field”. The term articulation has never been appropriately defined in the literature but it has been as a generic “complexity within a field” (Gilchrist and Annan, 2002, page 141). However, in a previous study (Soranzo and Agostini, submitted) it has been found that both photometric and geometric factors may affect lightness constancy even when the complexity within the field was not altered. In the present work we extend these investigations considering the belongingness factor. In particular, the aim of the present work is to clarify whether, keeping constant the complexity within the field, the simple manipulation of perceptual belongingness factors may affect lightness constancy by itself.

In order to analyse this issue, we measured the lightness similarity between two patches standing in different fields of illumination, by manipulating the spatial arrangement of some other patches standing in both fields.

2 Experiment

In this experiment we test the role of perceptual belongingness in lightness constancy. The basic configuration was a CRT simulation of a poorly articulated scene with two fields of illumination. We placed two patches, one in the bright, and the other in the dimly, illuminated field. As postulated by Katz (1911, 1935), in these poorly articulated cases the two patches should appear equal in lightness when the reflectance of the patch in light is lower than that of the other. In the experimental conditions we add to the basic configuration, six patches in each illumination field. Six of the patches were Squares and the other six were the same Squares rotated by 45 degrees (Diamonds). We manipulated the arrangement of the patches sharing the same shape in order to form a group within or across the two fields of illumination. The aim of this experimental manipulation was to find out whether lightness constancy is improved by the segregation or by the unification of the illumination fields.

2.1. Method

2.1.1 Observers

15 volunteer observers participated in this experiment. All had normal or corrected-to-normal vision and were naïve as regards the experimental design.

2.1.2 Apparatus and stimuli

The stimuli were all generated by a Pentium computer and were presented on a carefully calibrated 18-inch 523X Daewoo monitor (944 x 648 pixels). The basic configuration (see Figure 6) was constructed as follow. First, the screen of the monitor was vertically divided in two halves having different luminance (56 cd/m^2 for the left side and 5.6 cd/m^2 for the right side). Each half of the screen subtended 10 x 14 visual angle degrees. Then a rectangle (6.17 x 4.5 visual angle degrees) having a luminance equal to 79.8 cd/m^2 was positioned on the left half of the screen.

FIGURE 6 ABOUT HERE

A rectangle was drawn also on the right side of the screen; its luminance was equal to 7.98 cd/m^2. At this point, the screen was divided into four areas. The luminance ratio between the two areas on the left and the corresponding areas on the right was 10:1. Under these conditions, the edge dividing the two halves of the screen is perceived as an illumination edge and, therefore, the four areas are perceived as two surfaces (referred to as "inner" and "outer" background) under two different levels of illumination. This is a “light/shadow display” (Gilchrist and Annan, 2002). We will refer to the left side of the screen as the "light field" and to the right side as the "shadow field".

Finally, two squares (1 x 1 degrees of visual angle each) were placed in the middle of the two inner backgrounds: The square on the left was the target while that on the right was the standard. The luminance of the standard was 3.98 cd/m^2.

We had six experimental conditions. In each of them, there were twelve additional patches in the inner background, six Squares, and six Diamonds (1.2° x 1.2° visual angle each1). Six patches lay in light (three of them were placed at a 1.5° visual angle above the target, while the other three were placed at a 1.5° visual angle below it), and six were placed in shadow (three of them were placed at a 1.5 visual angle degrees above the standard, while the other three were placed at a 1.5 visual angle degrees below it). The horizontal distance amongst the patches was an experimental variable.

The luminance of each patch in light was equal to 70.3 cd/m^2, while that of each patch in shadow was equal to 7.03 cd/m^2. The patches had the same luminance ratio as the 2 halves of the backgrounds (10 to 1), therefore they had the same simulated reflectance.

We manipulated two variables:

- Belongingness, with 2 levels (a. Within the filed, b. Across the fields);
- Junction, with 2 levels (a. “X-junction” and, b. “no X-junction”).

Figure 7 shows the basic configuration and the six experimental conditions.

FIGURE 7 ABOUT HERE

In the first level of the Belongingness (Within the field) factor, all the squares were placed in light, while all the diamonds were placed in shadow. In this way, the additional patches sharing the same shape all lie within the same field of illumination.

[1] In order to get exactly the same size between squares and diamonds, we fitted an appropriate function taking into account that pixels width is smaller than pixels height.

In the second level (Across the fields), all the squares were placed in the upper part of the inner background, while all the diamonds were placed in the lower part. In this way, patches sharing the same shape constitute a row across the fields of illumination..

For the Junction variable, we manipulated the distance between the four additional patches (two in light and two in shadow) closer to the illumination edge. In the first level they were touching each other, in order to have an “X-junction”, or not touching, in order to have “no X-junction”. When they were not touching each other, the horizontal distance between them (from border to border) was equal to 0.2 visual angle degrees. This was the same horizontal distance occurring between the other patches in the same field. In forming an X-junction condition, the horizontal distance between the patches closer to the illumination edge and the other patches in the same field of illumination (from border to border) was equal to 0.3 visual angle degrees.

Summarizing, there were five displays, four experimental conditions plus the basic configuration.

2.1.3 Procedure

Observers viewed the stimuli, presented in random order, in a darkened room from a distance of 80 cm from the monitor. They were instructed to match the lightness of the target patch on the left side to the corresponding standard patch on the right side (see again figure 3) using the plus and minus keys of the keyboard. Pressing another button signalled that a satisfactory match was achieved; at that point, the target luminance was recorded and the next trial began. The luminance of the target was set to a random value at the beginning of each trial. In order to achieve a lightness match, we asked the observers to make the target patch "to look as if it were cut from the same piece of paper as the standard”. The observers performed four matches for each of the seven stimuli, so they provided twenty-eight adjustments. Each display was left on the screen as long as needed to produce the match. The whole session lasted about fifteen minutes.

2.2 Results and discussion

Mean ratings are expressed as the difference, in logarithmic units, between the experimental configurations and the basic condition, that served as a baseline. Observers’ mean ratings, together with the standard errors, are shown on figure 8.

FIGURE 8 ABOUT HERE

A repeated measure ANOVA reveals a significant main effect of the Belongingness factor [$F_{(1,14)} = 14.067$; p. < 0.01], while neither the Junction, nor the interaction between the two factors lead to a significant effect. It seems, therefore, that lightness constancy improves significantly only when the additional patches formed a row across the fields of illumination. This effect is not due to the number of the X-junctions characterizing the surfaces crossed by the illumination edges.

3. Discussion

The relation between perceptual belongingness and colour appearance has always been demonstrated by linking the two factors in contrast type displays. In the present work, we extend these investigations to the lightness constancy domain. In particular, our work was aimed to understanding if belongingness by itself affects constancy. Results show that when the grey elements standing in the two illumination fields are perceived as belonging to each other, lightness constancy is improved compared to both, the basic condition and the condition in which the elements constitute two groups each one forming a perceptual whole within its own illumination field. Furthermore, this effect does not dependent on the number of X-junctions.

In order to interpret this outcome, we propose that the strength of belongingness *across* the two illumination fields might help the visual system to aggregate in the lightness dimension surfaces sharing the same luminance ratio and, at the same time, to segregate the two fields in the dimension of apparent illumination.

The starting point of our interpretation is that, according to the scission theories (Bergström, 1977; Barrow & Tenenbaum, 1978, Gilchrist 1977; 1979; 1988; Gilchrist, Delman, & Jacobsen, 1983, Todd & Mingolla, 1983, Mingolla & Todd 1986, Bulthoff & Mallott, 1987; 1988; 1990; Anderson, 1997; Adelson, 2000; Sign and Anderson, 2002; Soranzo and Agostini, accepted), the visual system decomposes the pattern of light intensities reaching the eyes into separate contributions: Reflectance, illumination, transparency.

However, according to the albedo hypothesis (Kozaki, 1963, 1965; Oyama, 1968; Beck, 1972; Kozaki & Noguchi, 1976; Noguchi & Kozaki, 1985; Logvinenko & Menshikova, 1994, Agostini & Galmonte, 1997a, 1997b, 2002), in some conditions the visual system fails to attribute the luminance to the appropriate perceptual dimension: For example, part of the luminance that should have been attributed to the lightness is attributed to the apparent illumination, and/or, vice versa, part of the luminance that should have been attributed to the apparent illumination is attributed to the lightness.

Therefore, the losses of constancy can be considered a luminance *misattribution* occurring during the scission process.

Several factors seem to be relevant to reduce this luminance misattribution (Katz, 1911/1935; Katona, 1929; Henneman, 1935; Burzlaff, 1935; Gilchrist 1988; Bruno, 1994; Pessoa, Mingolla, and Arend 1996; Agostini, Soranzo and Galmonte, 1999; Soranzo and Agostini, accepted; Soranzo and Agostini, submitted). Belongingness across the illumination fields is a crucial factor, besides the others, to assign luminance to the appropriate perceptual dimension.

In a light/shadow type display, *ceteris paribus*, perceptual unification across the illumination fields strength the impression that the mid-edge is an illumination edge, which, in these cases, has the function to inform the visual system about the correct luminance attribution.

Recently, Palmer, Brooks and Nelson (2003) wrote: "We currently believe that such edge-grouping processes may play a significant role in lightness constancy processing by helping to disambiguate luminance edges either as reflectance or illumination edges" (page 327).

In the present work, we investigated this aspect showing that grouping process occurring among elements crossing the illumination edge are an important factor for lightness constancy. In fact, they help the visual system to aggregate luminances in the lightness dimension by forcing the equal reflecting, but differently illuminated surfaces to appear of the same lightness and, at the same time, to segregate luminances in the apparent illumination dimension by inducing the equal reflecting, but differently illuminated surfaces to appear differently illuminated.

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Figure Captions

Figure 1: The Benary configuration.

Figure 2: The Munker-White configuration.

Figure 3: The Agostini and Proffit configuration (common fate).

Figure 4: The Agostini and Proffit configuration (alignment).

Figure 5: The Agostini and Galmonte configuration.

Figure 6: a) Luminance of the stimuli (cd/m^2). b) Size of the stimuli (degrees of visual angle).

Figure 7. The basic configuration and the six experimental conditions arranged according to their belongingness level (columns) and to their Junction level (rows).

Figure 8. Results of the experiment. Mean ratings are expressed as the difference, in logarithmic units, between the experimental configurations and the basic condition. Bars indicate standard errors.